EVALUATION OF ELECTROMAGNETIC INTERFERENCE DUE TO AUTOMOTIVE REFLECTIVE GLAZING

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California Air Resources Board
Emission Research Section
Mobile Source Control Division
El Monte, California

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Abbreviations and Acronyms used in the Report

AB 32………………. Assembly Bill 32
All …………………….Reflective windshield, side windows, and rear window
ANOVA …………….. Analysis of Variance
ARB ………………… Air Resources Board
CDCR ……………….California Department of Corrections and Rehabilitation
CDMA ……………… Code Division Multiple Access
EM …………………. Electromagnetic
EMF …………………Electromagnetic Frequency
GPS ……………….. Global Positioning System
GSM ……………….. Global System for Mobile Communication
+R …………………. Reflective rooflight and rooflight cover closed
-R …………………… No reflective rooflight and cover closed
STOP ………………. Satellite Tracking of People
TTFF ……………….. Time to First Fix
Tts ………………….. Total Solar Transmittance
W Only ………………Reflective material only on windshield

EXECUTIVE SUMMARY

California's Global Warming Solutions Act, Assembly Bill 32 (AB 32), was signed into law in 2006 and requires reductions in California's greenhouse gas emissions to 1990 levels by the year 2020. The "Cool Cars" regulation, which aims to reduce the heat gain of vehicles parked in the sun thereby reducing the internal temperature and the need for air conditioning, was identified as an early action item under AB 32 and adopted by the Air Resources Board (ARB) in June 2009. Cool Cars specifies that vehicle windows must meet certain standards for heat transmission. Based on these requirements, ARB expects reflective glazing to be installed on windshields in 2012 and on all windows in 2016, unless automobile manufacturers decide to use an alternate performance option for 2016 and beyond. Reflective windows are known to attenuate electromagnetic waves. Staff researched what methods could be used to mitigate signal attenuation since reflective windows are currently used on vehicles sold today. Based on this research, staff determined that the Cool Cars regulation would allow for a portion of the reflective material to be removed in order to facilitate operation of electronic devices. Despite this allowance, concerns were still raised that devices such as global positioning system (GPS) monitoring ankle bracelets, cell phones, and GPS navigation devices will not operate as intended in vehicles with reflective glazing. ARB initiated a small test program to obtain first hand knowledge of the effect, if any, that reflective glazing has on these devices.

Testing was done in and around Los Angeles, CA in vehicles equipped with no reflective glazing, reflective glazing on the windshield only, and reflective glazing in all window positions. GPS navigation, GPS monitoring ankle bracelets, and cell phones were tested on a route that covered a variety of driving conditions including suburban, highway, and dense urban (i.e., urban canyons). GPS units were also tested by evaluating the time need to obtain a satellite lock, or time to first fix (TTFF), while parked and while driving in a suburban environment. The test results showed that the GPS monitoring ankle bracelets occasionally lost GPS signals in all vehicles regardless of the amount of reflective glazing, with drops averaging 2 minutes in length and no drop greater than 5 minutes. The cell phone back-up in the bracelets was able to determine the approximate location of the device every time the GPS signal was lost. GPS navigation data revealed that GPS devices are impacted by reflective glazing, but that navigation accuracy was improved by placing the device or an external antenna in the deletion window. Cell phone calls were not impacted in any way by the presence of reflective glazing. However, the cell phone test only evaluated the ability to make a phone call in an urban environment where cell phone signals are generally strong. GPS time to first fix results indicated that, as with navigation accuracy, the TTFF was impacted by reflective glazing. Vehicles with all-around reflective glazing had significantly longer TTFF than vehicles with a reflective windshield only or no reflective glazing. However, all impacts of reflective glazing on TTFF were mitigated by the use of a deletion window. In total, these results indicate that there are no effects of reflective glazing, and thus the Cool Cars regulation, on GPS monitoring ankle bracelets or cell phone usage in an urban environment. Although effects on GPS navigation units were observed, these effects were completely eliminated by placing the device or an external antenna within a deletion window.

I. INTRODUCTION

Assembly Bill 32 (AB32), signed into law in 2006, directs the Air Resources Board (ARB or Board) to reduce California's greenhouse gas emissions from virtually all sources. Greenhouse gases such as carbon dioxide (CO_2) are emitted when petroleum products are burned. Greater fuel consumption by engines and vehicles translates directly into greater CO_2 emissions. The use of air conditioners in motor vehicles substantially increases vehicular fuel consumption. Therefore, one way to reduce CO_2 emissions from motor vehicles is to reduce air conditioner use by lowering the heat gain from cars parked in the sun through a variety of solar management technologies.

The "Cool Cars" regulation, approved by the Board on June 25, 2009, aims to reduce the solar heat gain of vehicles parked in the sun by requiring manufacturers to equip new vehicles with solar control glazing. Solar control glazing is classified based on the total solar transmittance (Tts), or the percent of the total solar energy entering the vehicle through the glass compared to the total energy falling on the glazing. Reductions in Tts can be achieved through the use of tinting, solar reflective glazing, or solar absorbing glazing. The Cool Cars regulation specifies that, beginning in model year 2012, manufacturers must use 50 Tts windshields, 60 Tts side and back windows, and 30 Tts rooflights. Beginning with model year 2016, further control of solar heat gain is required. For this second tier of the regulation, reductions in solar heat gain can be achieved either through solar control of 40 Tts windshield, side, and back windows, and 30 Tts rooflights or through a performance-based option using a combination of solar control technologies resulting in equivalent solar performance achievable by the glazing alone. In addition to solar control glazing, several approaches to reducing solar heat gain have been identified, including solar reflective paints, passive or active ventilation systems, solar reflective or thermoregulating materials, and vehicle insulation. These and other technologies could be used as a potential means to meet a performance-based option.

At this time, the primary technology for achieving a window with 50 Tts or less is a metallic coating or film. This technology is also commonly referred to as solar "reflective" glazing. Because non-reflective alternatives meeting the 50 Tts requirement are limited, solar reflective glazing will likely be on most windshields beginning in 2012 and on the rest of the windows as well in 2016 assuming that manufacturers do not utilize the performance-based option. Solar reflective glazing is known to attenuate electromagnetic (EM) waves such as those used by global positioning system (GPS) devices, cell phones, garage door openers, and radar detectors. There are vehicles sold today that are equipped with solar reflective glazing. These vehicles are equipped with external antennas or have deletion areas[1] in the windows to allow for the proper functioning of these electronic devices. Therefore, to ensure the proper working of these electronic devices, the Cool Cars regulation allows for up to 10 percent of the treated area to be removed as necessary for purposes of increased electromagnetic

[1] "Deletion areas" are areas on a vehicle's glazing where part or all of the reflective material has been removed. These areas are specifically designed to facilitate transmission of electromagnetic signals into and out of the vehicle.

signal penetration. Despite this allowance, concerns that electronic devices will not function optimally in vehicles with reflective glazing have been raised. Additionally, there are possible public safety concerns should GPS signal attenuation prevent proper functioning of monitoring ankle bracelets worn by parolees or cell phone signal attenuation prevent people from making calls in emergencies.

At the time of the Cool Cars rulemaking, staff believed that signal attenuation concerns could be adequately addressed by the use of deletion windows and external antennas.[2] However, subsequent to the Hearing, some law enforcement groups questioned if solar reflective glazing would impact the efficacy of GPS ankle monitoring bracelets. Since this issue was not investigated prior to the Hearing, it was necessary for ARB to conduct a series of tests to determine how the Cool Cars regulation might impact this technology. To increase our understanding of how solar reflective windows might impact other electronic devices, cell phone and GPS navigation devices were included in the test program. The test program objectives were to: (a) determine the extent to which the performance of GPS navigation devices, GPS ankle monitoring bracelets, and cell phones are affected by solar reflective windshields only and solar reflective windows all around compared to a baseline vehicle not equipped with reflective glazing, and (b) evaluate the how the length of time needed to obtain a GPS satellite lock is impacted by reflective glazing, deletion windows, and external antennas.

II. METHODS

The methods used for evaluating electromagnetic frequency (EMF) signal attenuation are detailed in the project Test Plan (Appendix 1). Briefly, two sets of tests were conducted: (1) a driving test from ARB headquarters in El Monte to downtown Los Angeles (LA) during which GPS ankle bracelets, GPS navigation devices, and cell phones were tested, and (2) a test of GPS navigation device start-up times using a parked car test and a short drive path around El Monte. For the test of multiple devices along a driving path through downtown LA three vehicles were used: a BMW 528i (2008) as a control, a BMW 750Li (2007) with a solar reflective windshield only, and a Mercedes S 550 (2008) with all-around solar reflective glazing (Fig. 1). The solar reflective glazing on the Mercedes S and BMW 750 met 50 Tts specifications, and the windshields had small deletion areas around the rear view mirror as well as in the center near the dashboard to accommodate a radar detector, although this deletion window was too small to accommodate GPS test units. All vehicles had privacy glazing for the rear sidelights and backlight. All vehicles also had a non-solar control rooflight with an interior shade that was closed so as to completely cover the rooflight during the tests. In order to test the efficacy of a GPS-specific deletion window, BMW 528 was also equipped with a solar-reflective film on the windshield and rooflight for one trip and on all the windows, including the rooflight, for a second trip (Fig. 2). The estimated Tts of the film-covered glazing was 48 percent. A deletion flap of approximately 4 percent

[2] Staff Report: Initial Statement of Reasons (ISOR) for Rulemaking, Cool Cars Standards and Test Procedures, May 8, 2009, page 11. http://www.arb.ca.gov/regact/2009/coolcars09/coolcarsisor.pdf

of the total windshield area was cut in the passenger side lower corner to allow GPS testing with and without a deletion window (Figs. 2a, 3).

GPS navigation, ankle bracelets, and cell phone calling were simultaneously evaluated through a driving test that was conducted once with each vehicle on the same route (Fig. 4). The route went from El Monte to downtown LA and was chosen to enable testing of the devices under a variety of conditions including suburban surface streets, highway, and urban canyons. The routes to and from downtown were virtually identical, with a stop at a mid-way point in downtown LA where device configurations were changed.

GPS ankle monitoring bracelets were evaluated by placing two ankle bracelet devices, one from ProTech and one from Satellite Tracking of People (STOP), on surrogate ankles and placing those ankles in the passenger side footwell of the vehicle (Fig. 5). For the first half of the trip the bracelets were in the front footwell and for the return trip the bracelets were placed in the rear footwell. The expectation was that the only glazing configuration that would affect the bracelets in the rear footwell was all-around reflective glazing. The data were evaluated by downloading the location data collected during the drive tests to a computer and examining the route traces for drops in GPS satellite connectivity and route accuracy. The percentage of the time that the GPS signal was lost was calculated by dividing the total time the ankle bracelet was receiving a GPS signal by the total trip time.

Aftermarket GPS navigation functionality was evaluated using two Garmin Nuvi 7x5 devices. During the first leg of the tests with the manufacturer installed reflective glazing (Mercedes S and BMW 7), one GPS unit was placed in the center of the windshield and one unit was placed on the windshield on the driver's side above the dashboard. At the midpoint, the antenna was attached to the unit on the driver's side window and placed within the center deletion window and the second unit was moved from the center of the windshield to the passenger side corner above the dashboard. During the first leg of the test with the solar control film installed on BMW 528, one unit was installed on the passenger side windshield within the deletion window and the other unit was installed in the center of the windshield with the antenna attached and placed inside the deletion window. At the midpoint, the position of GPS units was unchanged although the film flap was closed thereby removing the deletion window and the antenna removed from the unit in the center of the windshield. The navigation ability was evaluated by downloading the completed route trace to a computer and examining the routes for drops in satellite connectivity and route accuracy. Route accuracy was calculated by dividing the total length of each track by the true route distance as measured in Google Earth to determine percent deviance from the actual route.

Cell phone functionality was evaluated by the ability to make phone calls of two minutes in duration at six points along a pre-determined route (Fig. 4). The route was chosen to maximize the distance between cell phone towers for the two major cellular frequency types, Code Division Multiple Access (CDMA) and Global System for Mobile Communications (GSM), thus maximizing the probability that cell phone communications may be interrupted. The two cell phone providers that were tested were Verizon and AT&T using a Motorola and Samsung phone respectively. The results from this test are binary, indicating only the ability to make a phone call or not.

GPS systems were also evaluated for time to first fix (TTFF), or the time it takes for the unit to lock onto sufficient satellites to obtain a position lock. The vehicle used for TTFF tests was an ARB fleet vehicle (Chevrolet Cavalier DS 2001). The tests were run in the vehicle with no reflective film (control), with reflective film on the windshield only, and with reflective film on all windows. The vehicle was not equipped with a rooflight. TTFF was determined by cold-starting GPS devices inside and outside of the deletion areas, as well as with and without an external antenna, and comparing lock times from the different vehicle types. The tests were performed first while parked and repeated over a driving course in the El Monte area (Fig. 6). The effect of the glazing type, deletion window, and antenna on TTFF was evaluated by analysis of variance (ANOVA) using JMP v. 8 (SAS Institute, Cary, NC). Significance was determined using a post hoc Tukey test and a significance level of $\alpha = 0.05$.

Figure 1. Photographs of three of the test vehicles. BMW 5 series was a control vehicle with no factory-installed solar reflective glazing. BMW 7 series comes standard with a solar reflective windshield. Mercedes S class comes standard with solar reflective glazing in all positions.

Figure 2. Picture of the solar reflective film installed on the windshield (a) and the rear passenger window (b).

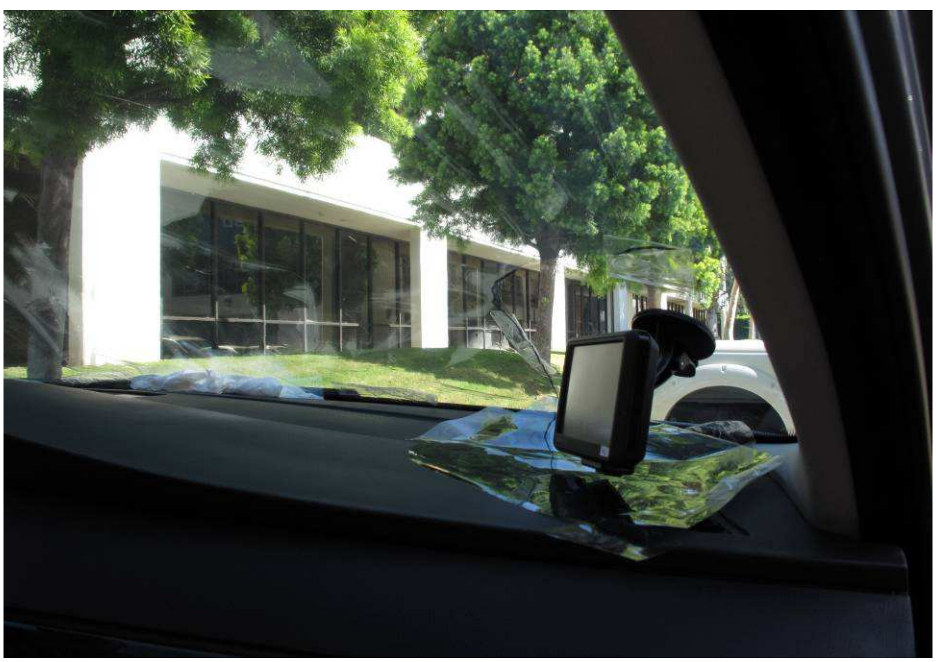


Figure 3. Close-up view of the deletion flap cut in the solar reflective film and GPS unit placed within the deletion window. The deletion window was measured at ~4 percent of the total windshield area.

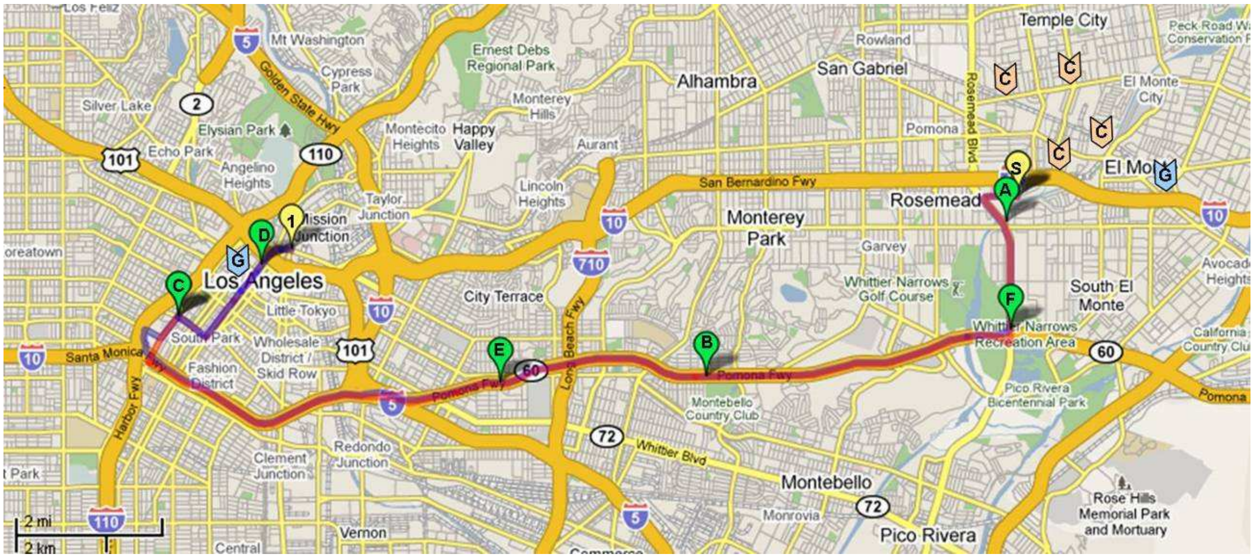


Figure 4. Map (from Google Maps) showing the route traveled on the driving tests of the GPS ankle bracelets, GPS navigation, and cell phones. The yellow balloons indicate the start point (S) and midpoint stop (1), green balloons indicate cell phone call locations, and chevrons indicate known positions of GSM (G) and CDMA (C) cell phone towers from http://www.cellreception.com.

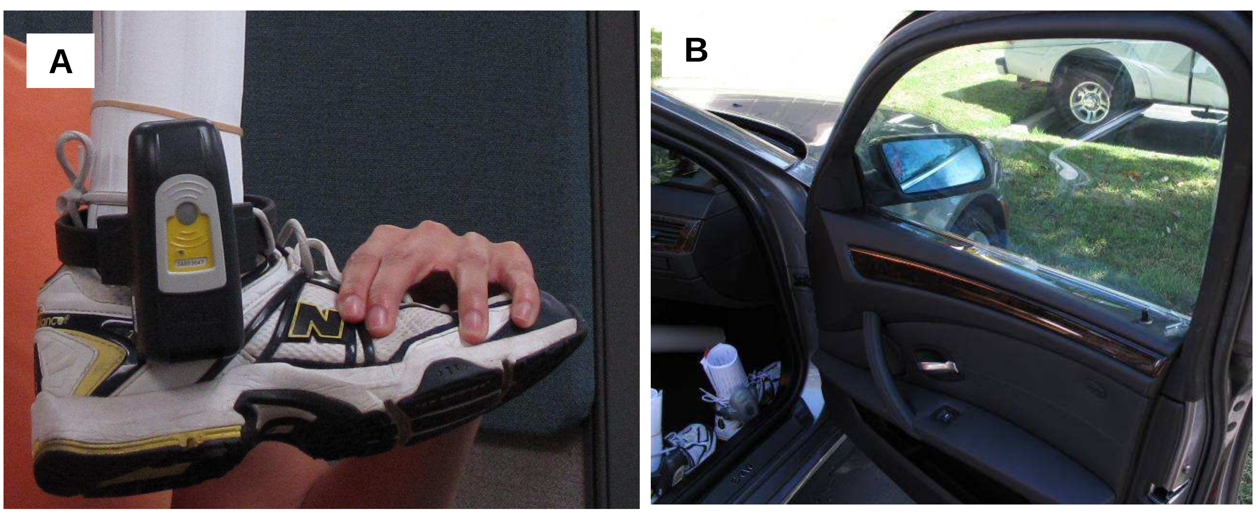


Figure 5. Close up photograph of the ProTech monitoring ankle bracelet on the surrogate ankle (a) and a photograph of the two ankle bracelets in the front passenger footwell at the beginning of a drive test in BMW 528 with all around solar reflective film.

Figure 6. Map (from Google Earth) of the route driven for TTFF GPS start tests conducted in El Monte. The circular route was 5.7 miles in length and passed under interstate 10 twice.

III. RESULTS AND DISCUSSION

A. GPS Ankle Bracelets

Inspection of GPS tracks indicated that GPS signals from both ankle bracelets were occasionally lost regardless of the presence of reflective glazing (Table 1). There were no clear trends in the length of time the signal was lost and increasing the area of reflective glazing, in large part due to high variability in the results (Fig. 7). Comparing individual test runs further highlighted the lack of trends. For example, the test runs with the greatest and smallest percentage of time dropped were both in vehicles where only the windshield had reflective glazing (Table 1). Another comparison revealed that the percentage of time GPS signal was dropped was virtually identical in a vehicle with no reflective glazing and a vehicle with all around reflective glazing (Table 1). The observed variability in GPS connectivity is indicative of travel through urban canyons, or streets that cut through dense blocks of structures causing a canyon effect.

Examination of the minute-by-minute results showed that GPS signal was most often lost in downtown Los Angeles, on a narrow street (Broadway) with tall buildings on either side. Signal loss on the freeways was associated with travel through interchanges. Although total trip signal loss was as high as 28 percent on a time basis, the majority of drops were one to two minutes in length with only four cases of drops four to five minutes in length. Additionally, the distance over which the majority of these losses occurred was small (2.2 miles) but the time required to travel this distance averaged 15 minutes, or 40 percent of the trip, due to the high density of traffic signals and vehicles. In all cases when GPS signal was dropped the approximate position of the bracelet was known due to the incorporated cell phone, which identified the closest cell phone tower and logged the tower position as the bracelet position. The cases when cell phone towers were used to determine position were not included in the calculation of GPS signal loss times presented in Figure 7, resulting in a "worse case scenario" for the signal loss data. If the cell phone tower-based locations were included in the analysis, it would show that at no time was the location unknown in any vehicle. These results indicate there is no effect of solar reflective glazing, and thus the Cool Cars regulation, on the efficacy of GPS monitoring ankle bracelets.

B. GPS Navigation Units

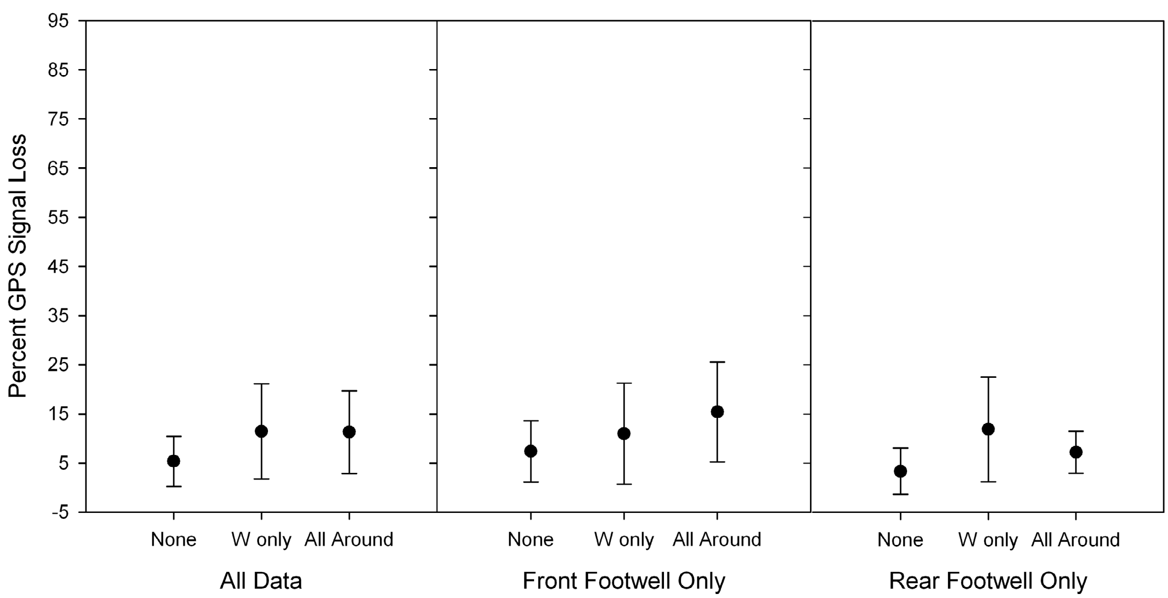
The percentage deviance of the paths was low overall, with the worst case of deviance occurring in the vehicle with no solar reflective glazing. With the exception of this case, the vehicles with solar reflective glazing generally had more deviance compared to the vehicle with no reflective glazing (Table 2). The least amount of deviance was observed under three scenarios: (1) in the vehicles with no reflective glazing, (2) when the device was placed within the deletion window of a vehicle with reflective glazing, and (3) when the external antenna was placed within the deletion window of a vehicle with reflective glazing. These results indicate that the reflective glazing did have an effect on GPS navigation ability, but the effect of the glazing was mitigated when the reflective glazing was removed. As with the ankle bracelet GPS, the majority of the navigation deviance occurred downtown in the area around Broadway due to multipath errors.

In all cases except the BMW 5 with 3.59 percent deviance, the GPS devices navigated the correct street or highway indicating that the GPS units are functional even without the use of deletion windows or external antenna. When the devices were placed within the deletion window or utilized an external antenna, the deviance averaged 1.3 percent, indicating that these solutions are effective in reducing the navigation error in vehicles with reflective glazing.

C. Cell Phone Calling

Three cell phone calls of two minutes in length were made using each cell phone carrier type (CDMA and GSM) in each of the three test vehicles (BMW 5, BMW 7, Mercedes S). In all cases the cell phone calls were successfully initiated and the quality of the call was rated as "good." The calls were never dropped. Although this is a simplistic test indicating only the ability to make and carry out a short cell phone conversation in urban areas, our results indicate that there are no effects of solar reflective glazing on cell phones. However, it is important to note that we did not measure signal attenuation directly and all testing was done in an urban environment where signal strength is generally very high. It is unknown whether or not reflective glazing would have an effect in areas where the signal strength is low due to lower tower density. While acknowledging these potential issues, it is also important to recognize that many European cars are equipped with all-around reflective glazing today. We are unaware of any cell-phone related “complaints” or concerns raised by the drivers of these vehicles. It is also likely that cell tower density, and thus signal strength coverage, will increase/improve by the time the second tier of the regulation begins in 2016 given the continual capital improvements by cell phone providers. Any improvement in signal strength coverage will further mitigate the potential issues with reflective glazing.

Figure 7. Mean ± standard deviation of the percentage of time the GPS signal was lost during the ankle bracelet test. Vehicles had a solar reflective windshield (W only), solar reflective glazing all around (All), or no reflective glazing (None). For half of the tests the bracelets were



placed in the front footwell for the greatest amount of obstruction from the vehicle dashboard and solar reflective windshield. For the other half the bracelets were placed in the rear footwell where the only likely glazing interference would be in the case of all-around reflective glazing.

Table 1. Percentage of time GPS signal was lost during the ankle bracelet test. Vehicles had a solar reflective windshield (W only), solar reflective all around except rooflight (All), or no reflective glazing (none). The rooflight of the vehicles did not contain solar reflective material (-R), but in several tests solar reflective film was additionally added to the rooflight (+R). During all tests the interior rooflight shade was closed completely obscuring the glazing.

Date	Vehicle & Glazing	Track	Ankle Bracelet Position	Start Time	End Time	ProTech Percentage dropped	STOP Percentage dropped
9/22/2009	BMW 7 W only (-R)	El Monte to Downtown	Front passenger footwell	12:48	1:25	0	5
9/23/2009	BMW 5 None	Downtown to El Monte	Rear passenger footwell	1:52	2:37	0	7
9/22/2009	BMW 7 W only (-R)	Downtown to El Monte	Rear passenger footwell	1:25	2:05	0	8
9/24/2009	BMW 5 All (+R)	Downtown to El Monte	Rear passenger footwell	2:22	3:08	2	11
9/23/2009	BMW 5 None	El Monte to Downtown	Front passenger footwell	1:18	1:52	3	12
9/24/2009	BMW 5 All (+R)	El Monte to Downtown	Front passenger footwell	1:47	2:22	6	9
9/23/2009	Mercedes S All (-R)	Downtown to El Monte	Rear passenger footwell	11:48	12:26	11	5
9/23/2009	Mercedes S All (-R)	El Monte to Downtown	Front passenger footwell	11:12	11:48	19	28
9/24/2009	BMW 5 W only (+R)	El Monte to Downtown	Front passenger footwell	11:56	12:35	23	15
9/24/2009	BMW 5 W only (+R)	Downtown to El Monte	Rear passenger footwell	12:35	1:15	25	15

Table 2. Percentage of distance GPS track deviated from the exact route driven. Vehicles had a solar reflective windshield (W only), solar reflective all around except rooflight (All), or no reflective glazing (none). The rooflight of the vehicles did not contain solar reflective material (-R), but in several tests solar reflective film was additionally added to the rooflight (+R). During all tests the interior rooflight shade was closed completely obscuring the glazing.

Date	Route	Vehicle	Reflective Glazing	GPS Unit	Unit in Deletion	Antenna in Deletion	Percent deviance
9/23/2009	ARB to LA	BMW 5	None	G1	No	No	3.59
9/23/2009	ARB to LA	Merc. S	All (-R)	G2	No	No	3.25
9/23/2009	ARB to LA	Merc. S	All (-R)	G1	No	No	2.90
9/22/2009	LA to ARB	BMW 7	W Only (-R)	G1	No	No	2.65
9/24/2009	LA to ARB	BMW 5	All (+R)	G1	No	No	2.65
9/24/2009	LA to ARB	BMW 5	All (+R)	G2	No	No	2.65
9/22/2009	ARB to LA	BMW 7	W Only (-R)	G2	No	No	2.56
9/22/2009	ARB to LA	BMW 7	W Only (-R)	G1	No	No	2.21
9/23/2009	LA to ARB	Merc. S	All (-R)	G2	No	No	1.96
9/22/2009	LA to ARB	BMW 7	W Only (-R)	G2	No	No	1.96
9/24/2009	LA to ARB	BMW 5	W Only (+R)	G1	No	No	1.96
9/23/2009	ARB to LA	BMW 5	None	G2	No	No	1.86
9/24/2009	LA to ARB	BMW 5	W Only (+R)	G2	No	No	1.61
9/24/2009	ARB to LA	BMW 5	W Only (+R)	G1	No	**Yes**	1.52
9/24/2009	ARB to LA	BMW 5	W Only (+R)	G2	**Yes**	No	1.52
9/23/2009	LA to ARB	BMW 5	None	G2	No	No	1.47
9/23/2009	LA to ARB	Merc. S	All (-R)	G1	No	**Yes**	1.26
9/24/2009	ARB to LA	BMW 5	All (+R)	G1	No	**Yes**	1.17
9/24/2009	ARB to LA	BMW 5	All (+R)	G2	**Yes**	No	1.17
9/23/2009	LA to ARB	BMW 5	None	G1	No	**Yes**	0.77

D. GPS Time to First Fix (TTFF)

Using a Chevrolet Cavalier with no reflective film, film on the windshield only, and film on all windows, the amount of time needed for GPS units to obtain a satellite fix was evaluated. The test was conducted with two units, one in the center of the windshield with and without an antenna, and one on the passenger side of the windshield inside and outside of a deletion window. Each configuration was tested while the vehicle was parked and while the vehicle was moving. An analysis of variance showed a significant effect of vehicle state (driving or parked) on TTFF, with driving resulting in longer average TTFF than when stationary. When we evaluated driving and parked results separately, we found that use of the antenna or deletion window resulted in no differences in TTFF between the different glazing types (Fig. 8). When the antenna was not used, the all-around reflective windows resulted in a greater TTFF than the windshield only or control vehicle while parked, although while driving there were no differences between the all around and windshield only TTFF, which were significantly longer than in the control vehicle. The deletion window was as effective as the antenna in keeping TTFF equivalent between all glazing types. When the deletion window was filled with reflective material and the vehicle was parked, the all-around reflective vehicle had the longest TTFF, followed by the windshield only and the control vehicle. While driving, there were no differences between TTFF when the device was within the deletion window or between any reflective glazing configurations (Fig. 8).

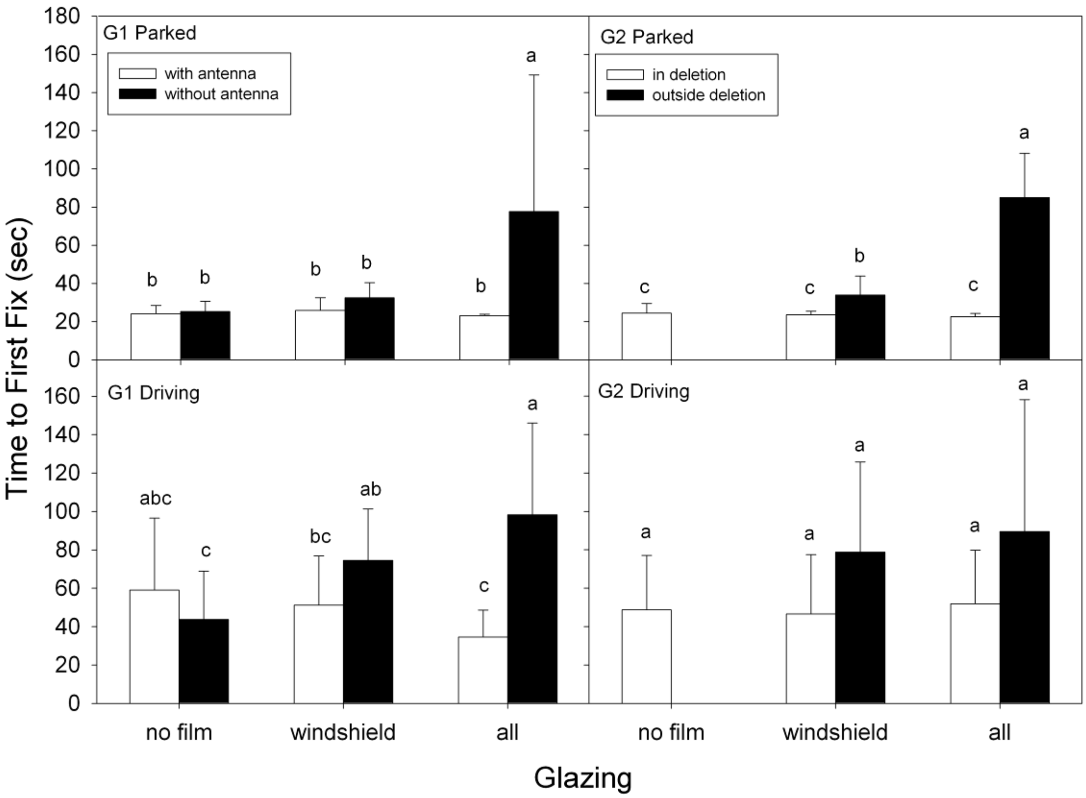


Figure 8. Mean + standard deviation of the time to first fix (TTFF) as measured in a Chevrolet Cavalier with no reflective film, film on the windshield only, and film on all windows. An analysis of variance conducted for each unit and vehicle state (driving or parked) indicated that reflective film did increase TTFF, particularly when applied to all windows. However, there was no significant effect of glazing when an antenna placed in the deletion window was used or when the unit itself was located in the deletion window. Significance was set at α= 0.05, and bars with the same letter are not significantly different from each other.

These results indicate that placing the device or an external antenna in the deletion window is an effective means of reducing TTFF in vehicles with reflective glazing. Although this TTFF drive test did not travel through areas with urban canyons, we would expect TTFF to be longer in all vehicles regardless of glazing type in areas with urban canyons due to multipath errors, similar to the results from the navigation test where the greatest track deviance occurred in the vehicle with no reflective glazing. Thus, the expectation is that, as with the navigation test, TTFF would be improved by the use of deletion windows in urban canyons as well. We also observed that, even without a deletion window, TTFF in vehicles meeting the 2012 regulatory requirement of a windshield with 50 Tts averaged about 20 seconds while parked and less than 80 seconds while driving. While it is unknown what is considered an unacceptable TTFF to consumers, these data indicate that a consumer can obtain a fix in under 1.5 minutes and once a fix is obtained, can successfully navigate to his or her destination as demonstrated in the GPS navigation tests.

IV. CONCLUSIONS

The results from this small-scale test of GPS navigation units, GPS monitoring ankle bracelets, and cell phones indicate that there are few significant effects of reflective glazing on the operation of these devices. The greatest effect of glazing was observed in GPS navigation devices, although these effects were completely mitigated by placing an antenna or the unit itself in the deletion window. Most significantly, no effect of reflective glazing was observed on the monitoring ankle bracelets. Although the ankle bracelets experienced GPS signal loss, the signal was consistently picked up by cell phone towers during these drops. This result coupled with the ability to make cell phone calls in all vehicles indicates that cell phone service and associated services such as emergency 911 that use assisted GPS (a combination of cell phone and GPS technology) are unlikely to be impacted in vehicles with reflective glazing in urban environments. Although the test results presented here are limited in replication and geographical scope, indications are that there will be limited impacts from the Cool Cars regulation on devices reliant on EM waves, particularly in the first tier when only the windshield may have reflective glazing.

Test Plan
EVALUATON OF RADIO FREQUENCY INTERFERENCE BY SOLAR REFLECTIVE GLAZING
Project # 2R0909

September 1, 2009

Revised October 1, 2009

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TEST PLAN

Introduction

The Cool Cars regulation, under California's Global Warming Solutions Act, requires the use of solar control glazing in vehicles beginning in model year 2012. The use of solar control glazing will reduce the solar heat gain of the vehicles while parked in the sun, thus reducing air conditioning usage and lowering greenhouse gas emissions. The most effective solar control glazing at this time is a solar reflective technology, which not only blocks incoming heat but also attenuates global positioning system (GPS) and cell phone frequencies. As a result, numerous electronic devices, including aftermarket GPS navigation units, cell phones, and parolee monitoring ankle bracelets, may not function in vehicles installed with reflective glazing in all positions. This test plan will allow the Air Resources Board (ARB or Board) staff to evaluate the extent to which functioning of electronic devices are affected by reflective glazing as proposed in the Cool Cars regulation. Specifically, staff will test GPS and cell phone operation in vehicles with standard glazing, glazing similar to tier 1 standards (i.e., windshield only with reflective glazing), and tier 2 standards (i.e., all windows with reflective glazing) to determine the extent to which GPS and cell phone operation is impaired by this type of glazing.

Proposed Test Periods

September 22, 2009 – September 24, 2009
October 5, 2009 – October 6, 2009

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A. Background

Assembly Bill 32, signed into law in 2006, directs ARB to reduce California's greenhouse gas emissions from virtually all sources. Greenhouse gases such as carbon dioxide (CO_2) are emitted when petroleum products are burned. Greater fuel consumption translates directly into greater CO_2 emissions. The use of air conditioners in motor vehicles substantially increases vehicular fuel consumption. Therefore, one way to reduce the CO_2 emissions from motor vehicles is to reduce air conditioner use by lowering the heat gain from cars parked in the sun through a variety of solar management technologies.

The "Cool Cars" regulation, approved by the Board on June 25, 2009, aims to reduce the solar heat gain of vehicles parked in the sun by requiring manufacturers to equip new vehicles with solar control glazing. Solar control glazing is classified based on the total solar transmittance

(Tts), or the percent of the total solar energy entering the vehicle through the glass compared to the total energy falling on the glazing. Reductions in Tts can be achieved through the use of tinting, solar reflective glazing, or solar absorbing glazing. The Cool Cars regulation specifies that, beginning in model year 2012, manufacturers must use 50 Tts windshields, 60 Tts side and back windows, and 30 Tts rooflights. Beginning with model year 2016, further control of solar heat gain is required. For this second tier of the regulation, reductions in solar heat gain can be achieved either through solar control of 40 Tts windshield, side, and back windows, and 30 Tts rooflights or through a performance-based option using a combination of solar control technologies resulting in equivalent solar performance achievable by the glazing alone. In addition to solar control glazing, several approaches to reducing solar heat gain have been identified, including solar reflective paints, passive or active ventilation systems, solar reflective or thermoregulating materials, and vehicle insulation. These and other technologies could be used as a potential means to meet a performance-based option.

The primary technology for achieving a window with 50 Tts or less is a metallic coating or film. As such, these metallic coatings or films will likely be on most windshields beginning in 2012 and likely be on most of the other windows as well in 2016 assuming that manufacturers do not utilize the performance-based option. Metallic coatings or films are known to attenuate radio frequencies such as those used by GPS devices, cell phones, garage door openers, and radar detectors. To ensure the proper working of these electronic devices, the Cool Cars regulation allows for up to 10 percent of the treated area to be removed. However, there is concern that electronic devices will not function optimally in vehicles with reflective glazing. Additionally, there are possible public safety concerns because GPS signal attenuation may prevent proper functioning of monitoring ankle bracelets worn by parolees and cell phone signal attenuation may prevent people from making calls in an emergency. Because there is little data available regarding the effects of reflective glazing on the functioning of electronic devices, including GPS ankle monitoring bracelets, ARB conducted a series of tests to determine how the Cool Cars regulation will impact these technologies.

B. Project Objectives

This project will: (a) determine how performance of GPS navigation devices, GPS ankle monitoring bracelets, and cell phones are affected by solar reflective windshields only and solar reflective windows all around compared to a baseline vehicle not equipped with reflective glazing, and (b) evaluate the performance of GPS navigation devices within and outside of the deletion window, and with and without an external antenna.

C. Approach

This project will test three types of electronic devices likely to be affected by the radio frequency blocking properties of solar reflective glazing. The three device types are cell phones, GPS navigation systems, and GPS ankle monitoring bracelets. The functionality of these devices will be evaluated in three vehicle types: no solar reflective glazing, solar reflective windshield only, and solar reflective glass in all positions. Each vehicle will be driven along a pre-determined route and all three electronic device types tested simultaneously in order to maximize test efficiency.

Cell phone functionality will be evaluated by the ability to make phone calls of several minutes in duration at six points along a pre-determined route. The route will be chosen to maximize the distance between cell phone towers for the two major cellular frequency types, Code Division Multiple Access (CDMA) and Global System for Mobile Communications (GSM), thus maximizing the probability that cell phone communications may be interrupted. Aftermarket GPS systems will be evaluated for time to satellite lock and navigation capability. The time to lock will be determined by cold-starting GPS devices inside and outside of the deletion areas, as well as with and without an external antenna, and comparing lock times from the different vehicle types. GPS navigation functionality will be evaluated by downloading the completed route trace to a computer and examining the routes for drops in satellite connectivity and route accuracy. The navigation system will be placed within the deletion window for half of the route and outside of the deletion window for half of the route. In addition, a second GPS device with an external antenna will be tested with the antenna detached for half the route and outside of the vehicle for half of the route. GPS ankle monitoring bracelet will be evaluated by downloading the location data collected during the drive tests to a computer and examining the route traces for drops in satellite connectivity and route accuracy. For half of the route the bracelets will be tested in the front footwell and during the remaining route the bracelets will be tested in the rear footwell of the vehicle.

D. Test Protocol

1. Vehicles and Equipment

1.1 Vehicles (*Rent vehicles and borrow from ARB Fleet*)
No reflective glazing – BMW 5 series
No reflective glazing – Chevrolet Cavalier
Solar reflective windshield only – BMW 7 series (2002-2008)
Solar reflective all around – Mercedes S class

1.2 Solar Reflective Film (*Southwall will provide film*)
One roll of reflective film

1.3 GPS Navigation (*Garmin will lend units*)
2 Garmin devices (one without an external antenna (unit 1) and one with an external antenna (unit 2))
2 laptops with GPS clearing software for the Garmin devices (Warm Start)

1.4 Cell Phone (*Borrow from ARB employees*)
1 CDMA cell phone (Sprint or Verizon)
1 GSM cell phone (T-Mobile or AT&T)

1.5 GPS Ankle Bracelet (*California Department of Corrections and Rehabilitation (CDCR) will lend units*)
2 Bracelets (*1 ProTech device, 1 by Satellite Tracking of People (STOP)*)

2. Preparation and Preconditioning

2.1 Test Vehicles: Measure all windows of the two vehicles without solar reflective windows (BMW 5 and Chevrolet Cavalier) and cut reflective film so that it will completely cover each window. For the windshield, cut a deletion window in the passenger side corner. Save flap so that the deletion window may be sealed to do “inside and outside deletion window” tests.

2.2 GPS Navigation: Leave devices off until entering the vehicle. For GPS time to first fix test, mount GPS unit 1 to the center windshield of the Chevrolet Cavalier and GPS unit 2 to the passenger side corner. For GPS navigation test, mount GPS unit 1 to the center windshield above radar detection deletion window and GPS unit 2 to the driver’s side corner windshield.

2.3 Cell Phones: Cell phones should be fully charged. While indoors, turn devices on > 5 minutes prior to entering the vehicle.

2.4 Ankle Bracelets: While indoors turn devices on > 5 minutes prior to entering vehicle. Place bracelets on surrogate ankles (i.e., boots).

3. Test Sequence

3.1. GPS Time to First Fix Tests (TTFF)

3.1.1. All windows must remain closed for the entirety of the test. Starting with the Chevrolet Cavalier with no reflective film, conduct start test with the two mounted GPS units (units 1 and 2). Hook up each unit to a laptop loaded with the Warm Start program. Enter the file name for the log output; file name should include date, unit number, unit position, glazing type, and use of antenna or deletion. Start the Warm Start program on each computer. After ten TTFF data points have been collected, shut down program.

3.1.2. Attach the antenna to unit 1 and place antenna in passenger side corner. No changes will be made to unit 2. Enter the file names for the next log outputs and start Warm Start program for each unit. After ten TTFF data points have been collected, shut down program.

3.1.3. Remove units from windshield. Place solar control film on windshield with deletion window on passenger side taped shut. Attach GPS unit 1 to the center windshield and GPS unit 2 to the passenger side windshield. Enter the file name for the next log output and start Warm Start program for each unit. After ten TTFF data points have been collected, shut down program.

3.1.4. Remove unit 2 from the windshield, remove the deletion window flap to expose deletion window, and replace unit 2 in the deletion area. Attach the antenna to unit 1 and place antenna in passenger side corner inside deletion area. Enter the file names for the next log outputs and start Warm Start program for each unit. After ten TTFF data points have been collected, shut down program.

3.1.5. Tape the reflective film on the remaining windows ensuring the entirety of each window is completely covered. Remove the antenna from unit 1, remove unit 2 from the deletion area, tape the deletion window flap over the deletion window, and replace unit 2 over the covered deletion area. Enter the file names for the next log outputs and start Warm Start program for each unit. After ten TTFF data points have been collected, shut down program.

3.1.6. Remove unit 2 from the windshield, remove the deletion window flap to expose deletion window, and replace unit 2 in the deletion area. Attach the antenna to unit 1 and place antenna in passenger side corner inside deletion area. Enter the file names for the next log outputs and start Warm Start program for each unit. After ten TTFF data points have been collected, shut down program.

3.1.7. Conduct the drive test. Starting with the all-around solar film car, remove the antenna from unit 1, remove unit 2 from the deletion area, tape the deletion window flap over the deletion window, and replace unit 2 over the covered deletion area. Enter the file names for the next log outputs and start Warm Start program for each unit. Drive along the pre-determined route (Figure A-1). Shut down the Warm Start program upon return.

3.1.8. Remove unit 2 from the windshield, remove the deletion window flap to expose deletion window, and replace unit 2 in the deletion area. Attach the antenna to unit 1 and place antenna in passenger side corner inside deletion area. Enter the file names for the next log outputs and start Warm Start program for each unit. After ten TTFF data points have been collected, shut down program. Drive along the pre-determined route (Figure A-1). Shut down the Warm Start program upon return.

3.1.9. Remove the reflective film from all windows except windshield. Remove the antenna from unit 1, remove unit 2 from the deletion area, tape the deletion window flap over the deletion window, and replace unit 2 over the covered deletion area. Enter the file names for the next log outputs and start Warm Start program for each unit. Drive along the pre-determined route (Figure A-1). Shut down the Warm Start program upon return.

3.1.10. Remove unit 2 from the windshield, remove the deletion window flap to expose deletion window, and replace unit 2 in the deletion area. Attach the antenna to unit 1 and place antenna in passenger side corner inside deletion area. Enter the file names for the next log outputs and start Warm Start program for each unit. After ten TTFF data points have been collected, shut down program. Drive along the pre-determined route. Shut down the Warm Start program upon return.

3.1.11. Remove the reflective film from windshield. Remove the antenna from unit 1 and replace unit 2 in passenger side corner where the deletion area would be in a solar control car. Enter the file names for the next log outputs and start Warm Start program for each unit. Drive along the pre-determined route. Shut down the Warm Start program upon return.

3.1.12. Attach the antenna to unit 1 and place antenna in passenger side corner inside deletion area would be. Make no changes to unit 2. Enter the file names for the next log outputs and start Warm Start program for each unit. After ten TTFF data points have been collected, shut down program. Drive along the pre-determined route. Shut down the Warm Start program upon return.

3.2. GPS Navigation test

3.2.1. Starting with the BMW 7, place unit 1 on the windshield by the driver's side corner and unit 2 on the windshield in the center above the radar detection deletion window. Start both units and travel on predetermined route (Figure A-2). All windows must be kept closed for the entirety of the test. At the mid-way point (stop 1 in Figure A-2), stop the vehicle, turn off each GPS unit, and change GPS configuration: attach the antennae to the unit 1 and place antennae inside deletion in center dash, move GPS 2 to passenger side windshield. Turn on both GPS units and continue on route to ARB in El Monte.

3.2.2. Upon return to El Monte, shut down both units before removing from vehicle. Take the units into the office and download each track log onto an office computer for upload into Google Earth 5.0 for viewing and analysis. Clear GPS memory.

3.2.3. Repeat steps 3.2.1 and 3.2.5 in the remaining two vehicles (Mercedes S and BMW 5).

3.2.4. Tape the solar control film on windshield of the BMW 5 with the deletion window on passenger side taped shut. Attach GPS unit 1 to the center windshield and GPS unit 2 to the passenger side windshield. Start both units and travel on predetermined route (Figure A-2). All windows must be kept closed for the entirety of the test. At the mid-way point (stop 1 in Figure A-2), stop the vehicle, turn off each GPS unit, remove the deletion window flap, and change GPS configuration: attach the antennae to the unit 1 and place antennae inside deletion window on passenger side, place unit 2 inside the deletion window. Turn on both GPS units and continue on route to ARB in El Monte.

3.2.5. Upon return to El Monte, shut down both units before removing from vehicle. Take the units into the office and download each track log onto an office computer for upload into Google Earth 5.0 for viewing and analysis. Clear GPS memory.

3.2.6. Tape the reflective film on the remaining windows ensuring the entirety of each window is completely covered. Remove the antenna from unit 1, remove unit 2 from the deletion area, tape the deletion window flap over the deletion window, and replace unit 2 over the covered deletion area. Start both units and travel on predetermined route. At the mid-way point stop the vehicle, turn off each GPS unit, remove the deletion window flap, and change GPS configuration: attach the antennae to the unit 1 and place antennae inside deletion window on passenger side, place unit 2 inside the deletion window. Turn on both GPS units and continue on route to ARB in El Monte.

3.2.7. Upon return to El Monte, shut down both units before removing from vehicle. Take the units into the office and download each track log onto an office computer for upload into Google Earth 5.0 for viewing and analysis. Clear GPS memory.

3.3. Bracelet Test Sequence (may be completed in conjunction with GPS navigation test, Section 3.2)

3.3.1. Starting with BMW 7, carry surrogate ankles with bracelets attached from the building to test vehicle. Place surrogate ankles on ground while opening front passenger side door.

3.3.2. Enter vehicle, place surrogate ankles in the passenger side foot well in the front of vehicle. Drive along pre-determined path (Figure A-2). At the mid-way point (stop 1 in Figure A-2), stop the vehicle, take the surrogate ankle + bracelet out of the car from the front passenger side, wait two minutes to (re)gain satellite lock, and move the surrogate ankle + bracelet to the rear passenger-side footwell of the vehicle for the return trip.

3.3.3. Retrieve surrogate ankles from the foot well, exit vehicle, and return to building.

3.3.4. Repeat steps 3.3.1-3.3.3 in the two remaining test vehicles (Mercedes S and BMW 5).

3.3.5. Repeat steps 3.3.1-3.3.3 in BMW 5 equipped with reflective film on the windshield and reflective film on all windows.

3.3.6. Meet with CDCR staff at the end of all test runs to download and examine route traces from the three runs.

3.4. Cell Phone Test Sequence (may be conducted in conjunction with GPS navigation test and GPS ankle bracelet test, Sections 3.2 and 3.3)

3.4.1. A passenger is required for this test. Passenger, equipped with 1 CDMA and 1 GSM cell phone, enters the first test vehicle and sits in the front passenger seat.

3.4.2. As the car moves along the pre-determined route, the passenger will make six phone calls of two minutes in length. Phone calls will be made at points A-F in Figure 2 and the quality and duration of the call noted on datasheet 2. CDMA phone will be used to make calls at points A, C, and E. GSM phone will be used to make calls at points B, D, and F. If the call is dropped prior to the end of the phone call, the passenger will note the duration of the call prior to being dropped.

3.4.3. Repeat procedure steps 3.3.1-3.3.2 with each test vehicle.

4. Data Analysis

4.1. GPS Start Tests

4.1.1. Startup tests will be analyzed using analysis of variance to determine if there is a significant effect of solar reflective film, vehicle state (driving or parked), or deletion windows on length of time until satellite lock.

4.2.2. Prior to conducting analysis of variance, data will be transformed as necessary to conform to the assumptions of the test. Each effect will be tested individually, in combination, and with interactions. Significance will be set at an alpha = 0.05 and evaluated with a post hoc Tukey test.

4.2. GPS Navigation

4.2.1. Drive test will be analyzed by uploading all track data to Google Earth. The percent deviation from the actual road traveled will be compared for each half-track, where the half-track is defined as the total distance traveled between the start point and the midway point or the midway point to the end point.

4.3. Ankle Bracelet

4.3.1. With assistance from CDCR, each bracelet track will be compared with the actual track traveled. The number and lengths of any breaks in data acquisition will be noted for each test track. Only a semi-quantitative comparison between the vehicles will be possible given the form of data output.

4.4. Cell Phone

4.4.1. The number of dropped calls will be compared between the test vehicles and correlated to the distance from known cell phone towers. Known cell phone tower locations will be obtained from http://www.cellreception.com. A qualitative comparison of call quality will also be conducted between vehicle types.

Appendix 1

Radio Frequency Attenuation by Solar Reflective Glazing
Test Plan Datasheet 1: Cell Phone Test

Date ________________________________ CDMA Phone Model: ______________________

Recorder (name) ______________________ GSM Phone Model: ______________________

Test 1	[1]Vehicle Model: B3 B7 MS	Start Time:	End Time:
Cell Phone Test	Location	[2]Call Quality	Call Duration
CDMA Phone	Point A		
GSM Phone	Point B		
CDMA Phone	Point C		
GSM Phone	Point D		
CDMA Phone	Point E		
GSM Phone	Point F		
Test 2	[1]Vehicle Model: B3 B7 MS	Start Time:	End Time:
Cell Phone Test	Location	[2]Call Quality	Call Duration
CDMA Phone	Point A		
GSM Phone	Point B		
CDMA Phone	Point C		
GSM Phone	Point D		
CDMA Phone	Point E		
GSM Phone	Point F		
Test 3	[1]Vehicle Model: B3 B7 MS	Start Time:	End Time:
Cell Phone Test	Location	[2]Call Quality	Call Duration
CDMA Phone	Point A		
GSM Phone	Point B		
CDMA Phone	Point C		
GSM Phone	Point D		
CDMA Phone	Point E		
GSM Phone	Point F		

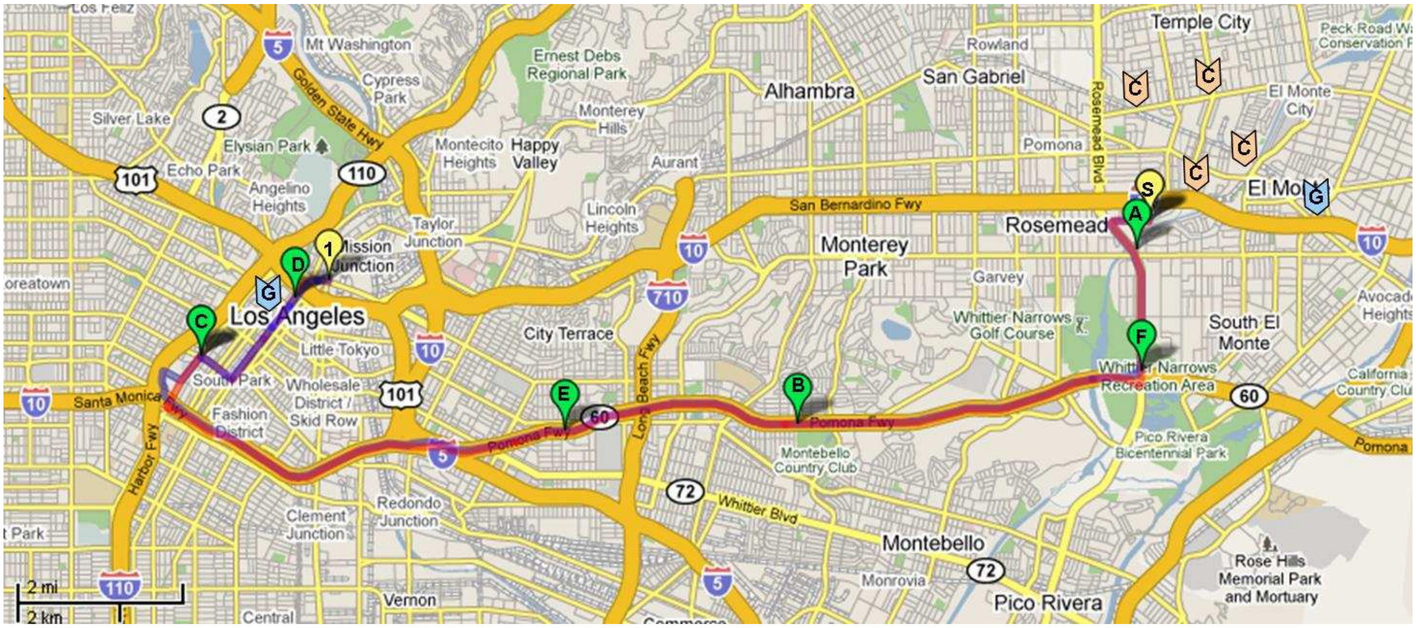
[1] Vehicle models: B3 = BMW 3 series, B7 = BMW 7 series, MS = Mercedes S class
[2] Call quality codes: G = good (no problems), S = static or problems with connection, D = dropped, N = not able to make call. Use multiple codes as appropriate.

Figure A-1. Map of the test track (blue line) for the GPS time to first fix tests.

Turn by Turn Directions

1. Head west on Telstar Ave toward Rio Hondo Ave - go 0.5 mi
2. Turn right at CA-19/Rosemead Blvd - go 1.4 mi
3. Turn right at Lower Azusa Rd - go 0.9 mi
4. Head south on Temple City Blvd toward Bisby St - go 0.6 mi
5. Turn left at Valley Blvd - go 0.4 mi
6. Take the 3rd right onto Baldwin Ave - go 0.5 mi
7. Baldwin Ave turns right and becomes Flair Dr - go 0.9 mi
8. Turn left at Aero Jet Ave - go 0.2 mi6Turn left at Telstar Ave - go 0.4 mi

Figure A-2. Map of the test track (blue line) and location of GPS swap-out (yellow "1" balloon) and cell phone call points (green balloons A-F). Cell phone towers closest to call points are indicated with chevrons (blue = GSM, pink = CDMA). The start and end location, ARB in El Monte, is indicated with a yellow "S" balloon.



Turn-by-Turn Directions:

Start at: 9480 Telstar Ave El Monte, CA 91731

1. Head west on Telstar Ave toward Rio Hondo Ave - 0.5 mi
2. Turn left at CA-19/Rosemead Blvd - 1.8 mi **(Begin Call A)**
3. Merge onto CA-60 W via the ramp to Los Angeles - 9.9 mi **(Begin Call B at exit 6B)**
4. Continue on I-10 W - 2.3 mi
5. Take exit 13 for Harbor Fwy/CA-110/I-110 toward San Pedro - 0.3 mi
6. Keep right at the fork, follow signs for PICO Blvd - 0.3 mi
7. Slight right at Cherry St - 482 ft
8. Turn right at W Pico Blvd - 0.2 mi
9. Turn left at S Figueroa St - 0.4 mi **(Begin Call C)**
10. Head southeast on W Olympic Blvd toward S Flower St - go 0.5 mi
11. Turn left at S Broadway - go 1.6 mi
12. Turn right at W Cesar E Chavez Ave - go 0.1 mi
13. Turn left at N Main St - go 423 ft
14. Turn right at N Alameda St - go 233 ft

Arrive at: 901 N Alameda St Los Angeles, CA 90012 **(Stop 1; Chevron Station)**

15. Head south on N Alameda St toward E Cesar E Chavez Ave - go 95 ft
16. Turn right at E Cesar E Chavez Ave - go 0.2 mi
17. Slight left at W Cesar E Chavez Ave - go 161 ft

18. Turn left at N Broadway - go 1.6 mi **(Begin Call D)**
19. Turn right at W Olympic Blvd - go 0.5 mi
20. Turn left at S Figueroa St toward W 11th St - 0.8 mi
21. Turn left at W 18th St - 479 ft
22. Turn left to merge onto I-10 E - 2.6 mi
23. Slight right at CA-60 E (signs for CA-60/I-5/Pomona) - 9.4 mi **(Begin Call E at exit 2)**
24. Take exit 10A for Rosemead Blvd - 0.3 mi **(Begin Call F)**
25. Turn left at CA-19/Rosemead Blvd - 2.1 mi
26. Turn right at Telstar Ave Destination will be on the right - 0.5 mi

Arrive at: 9480 Telstar Ave El Monte, CA 91731